國立交通大學

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碩 士 論 文

應用於無線網路之避免熱點的中繼點選擇方法

Hot-Spot Avoidance Relay Selection in Wireless Ad Hoc Networks

研 究 生：張銘丞

指導教授：趙禧綠　助理教授

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應 用 於 無 線 網 路 之 熱 點 避 免 的 中 繼 點 選 擇 方 法

Hot-Spot Avoidance Relay Selection Scheme in Wireless Ad-Hoc Networks

研 究 生：張銘丞　　Student：Ming-Cheng Chang

指導教授：趙禧綠　　Advisor：Hsi-Lu Chao

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摘要

在所有解決傳送衰落的方法當中，合作扮演了一個很重要的角色。在合作網路中，有許多中繼點選擇策略，諸如隨意、輪流、和優先權選擇。在優先權選擇策略(封包錯誤率大小、距離遠近、等等)中，擁有最高優先權的節點將會負責中繼傳輸。但這會產生一個問題。一個擁有繁重傳輸量的節點會變成一個瓶頸，這種情況將對傳輸狀況產生影響。這種瓶頸我們叫做熱點狀況，產生熱點狀況的節點就叫做熱點。

在這篇論文裡面，我們針對優先權選擇策略。收到一個封包時，節點會藉由收到封包的相關參數計算這次傳送的訊雜比，接著推導出相對應的封包錯誤率。在封包傳送之前，節點會選擇最低錯誤率相對應的點，當作他的中繼點。這種方法可以簡稱封包錯誤率大小選擇。本於這種方法，爲了要處理熱點狀況，我們設計一種測試去檢查所有可以被選擇的點，以避免熱點狀況的發生。檢查完之後，才來應用封包錯誤率大小選擇，來決定中繼點。

這裡提出一個稱爲熱點避免的中繼點選擇方法，簡稱 HARS。HARS 可以在無線網路環境下達到流量平衡。模擬結果顯示他有能力避免熱點狀況發生，而且在某些容易形成熱點狀況的環境中，做到比較有效率的傳送環境。

Abstract

Cooperation mechanism is one of the solutions to the problem of transmission fading. In cooperation network, there are several strategies to do relay-selection, such as random, round-robin, and priority-based. In priority-based strategy, the node with the highest priority takes more responsibility for relay action. That may produce a problem. A heavy-traffic node may result in a bottleneck which has a bad impact on the transmission performance. This bottleneck is called hotspot condition and the node on which hotspot condition rises is called hotspot.

In this paper, we aim at priority-based strategy. While receiving a packet, every node calculates the signal-to-noise ratio (SNR) and then derives its own packet error rate (PER). Before transmitting its packets, it selects its relay node with the smallest PER value. This method is also called "received-PER" strategy. Based on received-PER, in order to deal with hotspot condition, a test is designed to check all available nodes to avoid occurrence of hotspot condition. Then, received-PER strategy is applied to decide a relay node.

This proposed method is named hotspot avoidance relay selection scheme (HARS). HARS may attain a balanced traffic load in wireless transmission environment. Simulation results show that it is able to provide a hotspot-avoided environment and it is capable of getting better transmission efficiency in scenarios which tend to grow hotspot conditions.

致謝

或許是能力問題，或許什麼關鍵還沒突破，也或許是一開始規劃的太大，實作時卻想的不夠仔細，總而言之，這次的研究成果不能算成功，離我最初想完成的目標仍有不少差異．

作研究最讓人氣餒的事情，就是模擬結果不佳．也讓我不得不一直更改論文目標，以及論文內容關於設計以及計算的部份．在這段時間，很高興有 lab 成員可以聊天解悶，也很感謝家人一直的加油打氣．

我能完成我的碩士論文，首先該感謝老師幫我定出研究方向，並在關鍵的地方做出決定．也感謝實驗室的同學，是很好的討論對象．

Contents

List of figures

List of tables

Chapter 1. Introduction

People use the wireless network without wired-line, but the atmosphere as a medium. Information is transformed into electromagnetic wave first, and then transmitted in the air. However, transmission in the air may come across many unexpected conditions. Interference is absolutely included in them either with the environment noise or the other electromagnetic waves. When interference happens, error occurs frequently and the receiver who detects the wrong incoming packets is going to do nothing but dropping them. That causes a big error or dropping rate, and the whole transmission efficiency goes down. However, one of what mostly degrades the channel quality is so-called “fading” which comes from multipath or Doppler effect.

A well-known technique named multiple-input multiple-output (MIMO) is developed to solve this problem in the form of spatial diversity. However, it requires every node equipped with multiple antennas which results in hardware costs. In order to maintain the same diversity gain without those redundant antennas, a new strategy called “cooperation” is brought out.

In traditional wireless mechanism, a node only receives a packet with correct content in the incoming packet’s destination address field but drops it when the content of destination address field does not match, that means any node is only able to accept what are destined for it of all the incoming packets, and all the others ought to be treated as wrong packets and then discarded. If cooperation is taken into consideration, a new and important role named “relay node” is necessary to be added.

Once a node A is labeled by node B as a relay node, not only the packets for A but also those transmitted by B are all received by A (Fig 1-1). Then, the packets for

A are transmitted to the upper layer while those for B are waiting to be re-sent, and the others are viewed as wrong packets and then discarded.

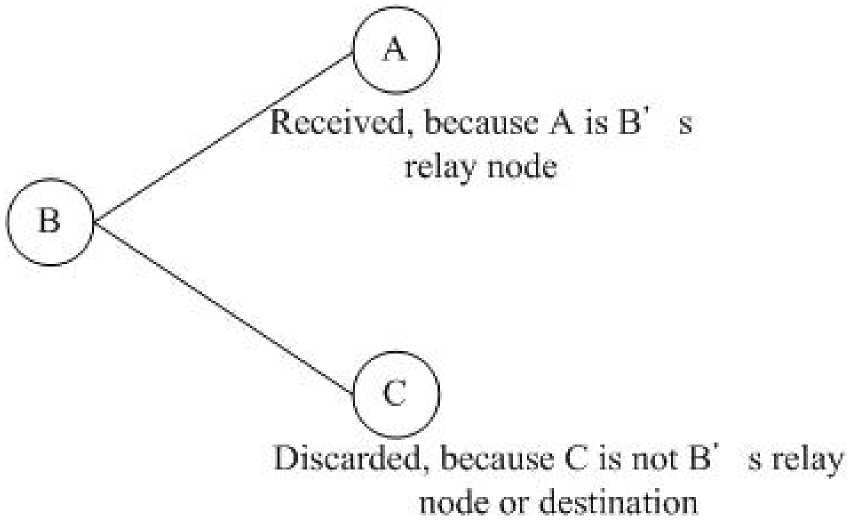

Fig. 1-1 A simple illustration of cooperation

The main difference between the traditional wireless and the cooperation system is the error-handle mechanism. In traditional wireless, when the receiver got an error packet, that packet is discarded, and then the source is about to transmit the same packet later. However, this error-handle mechanism is quite different in cooperation mechanism. Because of the cooperation from the relay node, the destination may receive two packets, if one of them is correct, the whole transmission process is considered correct. That means the re-transmission procedure is not necessarily required to do error-handle.

It is obvious that the cooperation benefits the quality of transmission while the direct link between the source and the destination fails or drops into a bad transmission status. It improves the performance of throughput, transmission delay, and error rate by going through another link which the relay node takes a great role as a bridge.

Nevertheless, another problem occurs. In ad hoc network, every node is able to be a source node and transmit its own packets. For any node, being selected as a relay of someone means more packets of other's own will be stored and sent by this relay node. The more source nodes who view this one as their relay, the more and more packets overheard and passed by this node. That results in a busy and heavy traffic there, and deduces that this node is a hot spot (Fig.1-2). That leads to a higher dropping rate in hotspot node and a lower transmission success ratio in receiver, both of which cause a deadly threat in wireless transmission. Especially in ad hoc network, hot spot creates a transmitting congestion and makes the routing paths going through it unstable and less efficient.

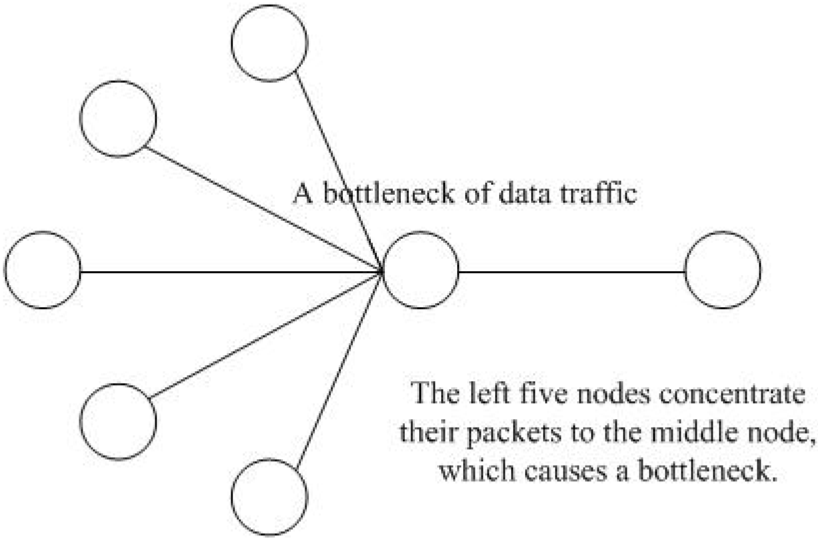

Fig. 1-2 Simple Illustration of hotspot occurrence

It is notable that the situation becomes deadly serious in priority-based relay selection strategy. Every node has its own priority table. In some scenario or topology, their priority sequence may in agreement with one another mostly. There is a high probability of hot spot occurrence. Therefore, the simulation and method proposed in this paper are all based on this strategy.

The architecture of this paper is followed. Chapter 2 lists some related works of cooperative network researches. Chapter 3 describes the system overview, data structure utilized in the simulation, and a new relay selection scheme which takes hot spot avoidance into account. Chapter 4 shows the simulation and provides analysis relatively. Chapter 5 reveals the conclusion and the future work.

Chapter 2. Related Work

There are many topics worthy of discussion and research.

In [1], the authors produce a closed form of symbol error probability (SEP). They validate that their resulting expressions are suitable for arbitrary number of relay nodes and arbitrary number of hops per relay route (Fig. 2-1) step by step. They start their validation by signal-to-noise ratio (SNR). Then use Q-function and Gamma function as helpers to calculate the behavior of average SEP based on the assumption of high SNR environment. Finally, a SEP expression for multi-relay and multi-hop environment is proposed as follows.

$$\overline{P} \approx \frac{C(M)(K+1)^{M+1}}{K^{M+1}} \cdot \frac{1}{SNR_{sd}} \prod_{i=1}^{M} \left(\sum_{j=0}^{N} \frac{1}{SNR_{ij}} \right) \qquad (1)$$

where M and N represents the number of relay routes and the hop count per relay route respectively, K denotes specular factor, and

$$C(M) = \left(\prod_i (2i-1)\right) \Big/ \left(2(M+1)!K^{M+1}\right). \qquad (2)$$

Many papers including some of the following ones use (1) to predict the system SEP (symbol error probability) or SER (symbol error rate) to execute their relay selection schemes.

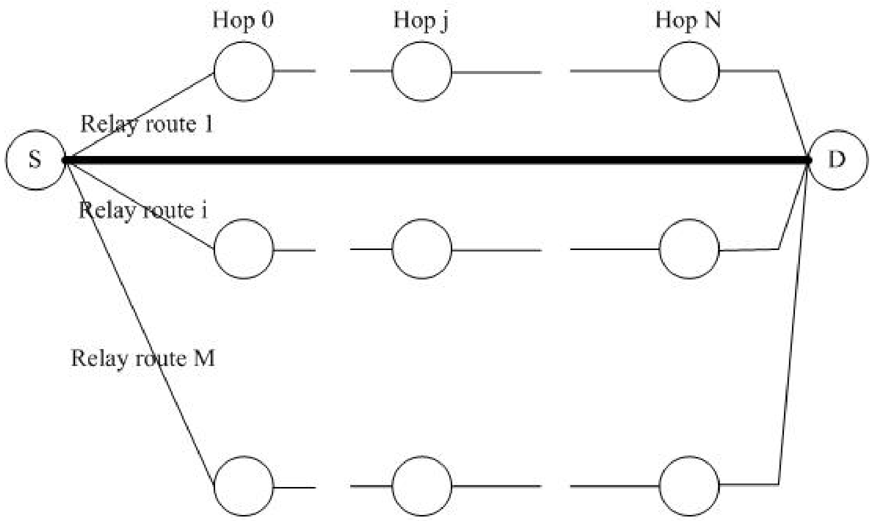

Fig. 2-1 Topology of a general cooperation mechanism

In [2], the authors focus on the optimal power allocation. They slightly modify the SEP formula (1) as their own one (2) to be suitable for their study on the topic about power allocation.

$$P_{sd} \approx \frac{C(M)}{k^{M+1}} \cdot \frac{1}{\beta_s \cdot SNR_{sd}} \prod_{i=1}^{M} \left(\frac{1}{\beta_s \cdot SNR_{si}} + \frac{1}{\beta_i \cdot SNR_{id}} \right) \tag{3}$$

where β_i is the power allocation factor for node i, and other variables are the same meanings as (1). Note that

$$0 \leq \beta_i \leq 1 \tag{4}$$

for i=1,…,M

$$\sum_{i=1}^{M} \beta_i = 1 \tag{5}$$

In [3], the same authors as in [2], three power allocation algorithms, centralized, distributed, and distributed with partial CSI, are transformed into three optimization problems respectively. They are (5), (6), and (7).

$$\min \frac{1}{M}\sum_{i=1}^{M} P_{sd}(\beta_i) \qquad (6)$$

$$\min \frac{1}{M}\sum_{i=1}^{M} P_{sd}(\beta_i)\,|_{\beta_i^{\,k}=\beta_i^{\,k-1}} \qquad (7)$$

where $\beta_i^{\,k}$ means the power allocation factor of node i in the k-iteration.

$$\min P^i(\beta_{n,m})\,|_{\beta_{j,m}=\beta_{j,m}^{\;i-1}} \qquad (8)$$

where $\beta_{j,m}^{\;i}$ means the power allocation factor of node j in the i-iteration.

All these three are subject to (3) and (4). (Note that the contents on [2] are inherited by [3], so their valuables have the same meanings.)

Next, the authors of [4] are interested in when to cooperate. In their design, the source node is responsible for making decision on whether to enter the cooperation mode or not. Let $\lambda_{s,r}, \lambda_{s,d}$ be the value of SNR between the source and the relay, and between the source and the destination. The source node compares a threshold α to the ratio $\frac{\lambda_{s,d}}{\lambda_{s,r}}$. If $\frac{\lambda_{s,d}}{\lambda_{s,r}} \geq \alpha$, then the source decides to transmit directly without any help of relay node. Otherwise, cooperation is applied. They also design their closed form of symbol error rate (SER), and do many experiments to find the best values of α in all kinds of environments. Besides, power saving is considered as a metric as well as the SER to select the best relay node.

The authors of [5] present a dynamic relay-selection algorithm. In order to judge whether the non-cooperation system should go into the cooperation mode or a cooperation system should be added another relay node, a threshold is adopted. In a traditional wireless environment, if the SER is worse than the threshold, then the source begins to pick up a node with the lowest SER as its relay and sorts the remaining unselected nodes in the order of SER. The source node constantly chooses a relay and sorts the remainders until the system SER is not worse than the threshold. The authors take on (1) as their SER expression.

In [6], three different relay selection strategies, which are random selection, received-SNR selection, and fixed priority selection, are mentioned and put together with the non-cooperation to compare their error rate.

In [7], the authors pay attention to hotspot condition and propose two approaches to mitigate it. They define throughput of a node as the ratio of the number of packets successfully transmitted by the node to the node's traffic load as follows.

$$n = \frac{n_{st}}{n_t + n_r + n_o} \tag{9}$$

where n_{st} means the number of packets successfully transmitted. And n_t, n_r, n_o represent the number of packets transmitted, received by the node, and overhead respectively. Then, the inverse of n is able to be divided into three parts. Those are $\frac{n_t}{n_{st}}$, which gives the indication of the number of errors, $\frac{n_s}{n_{st}}$, which indicates the number of packets in queue, and $\frac{n_o}{n_{st}}$ indicating a MAC contention. All those three parts are combined as n_{inv} and viewed as a metric.

$$n_{inv} > \lambda \tag{10}$$

where λ is a threshold. Once (9) is satisfied, this node is assumed to be under the hotspot condition. One of the solutions is avoid route request while hotspot occurs, and the other one is to suppress the creation of new route which goes through the hotspot.

Chapter 3. Hotspot Avoidance Relay Selection Scheme

3.1 Background and formula derivation

This paper focuses on single relay selection rather than multi-relay.

For a received-PER relay selection strategy, the most vital part is how to predict the error rate.

In order to obtain the reasonable error rate, some calculations have to be done. Once the signal-to-noise ratio (SNR) is computed from the received signal power and the interference, it is sufficient to get the packet error rate (PER) by the SNR and modulation type.

The SNR formula is in the following.

$$SNR = 10 \times \log_{10}\left(\frac{signal}{interference}\right) \tag{11}$$

PER formula is too complicated to be presented here, and the detailed procedure is on [8].

3.2 Data structure

Once the relay selection procedure is over, the source node has to make the relay node aware of what role it should take. Consequently a packet structure named "HELLO" is created (Fig. 3-1) for the purpose of informing every node of one's responsibility.

```
Struct hello_frame{
        struct frame_control hf_fc;
        u_int16_t hf_duration;
        u_char hf_ra[ETHER_ADDR_LEN];
        u_char hf_ta[ETHER_ADDR_LEN];
        int relay_ID[NODE_NUMBER];
        double ER_[NODE_NUMBER];
}
```

Fig. 3-1 Data structure of hello frame

The items of the hello frame are all the same as RTS frame except the last two ones. relay_ID field indicates who will be the relay for this node. If node i is chosen as a relay of this node, then the value of relay_ID[i] is “1”, or it shall be “0”. ER_ field stores the value of calculated error rate of every link from this node to all the others. ER_[j] means the numeric value of error rate between this node and node j.

Additionally, every node should maintain a relay table (Fig. 3-2) to record every node’s Hotspot Degree which takes great part in the hot-spot avoidance relay selection scheme introduced later, packet error rate of all the pairs in this environment, and a list to record whose packets should relay through this node.

```
Struct relay_table{
        int HD[NODE_NUMBER];
        double PER[NODE_NUMBER][NODE_NUMBER];
        int responsible_for[NODE_NUMBER][NODE_NUMBER];
}
```

Fig. 3-2 Data structure of relay table

The “HD” field records how many times a node being a relay. If HD[i] = 10, then we know that node i has been already selected as someone’s relay node 10 times. The method of how to maintain this value simultaneously above all the nodes will be introduced in sub-section (4).

The “PER” field provide the packet error rate of any link. If PER[i][j] = 0.01, then the packet error rate between node i and node j is 0.01. The value of this field needs to be updated simultaneously as well. The detail of the updating procedure will be in sub-section (4).

The responsible_for field informs a node of its responsibility for relay. It is obvious that if responsible_for[i] = 1, the node must be aware of the packet from node i even if this packet is not for this node.

3.3 MAC frame field

In IEEE 802.11 spec. [9], all the MAC frames are categorized into three types: management, control, and data frame. By the meaning of hello frame, it absolutely belongs to control frame. Note that whether the control type or management type, there are still many sub-types created for different purposes, and each sub-type is allocated a unique identifier in its belonging type.

In order to make hello frame identifiable in 802.11 wireless network and does not interfere with other well-defined control frames such as RTS, CTS, ACK, etc. An unused identify is necessary for hello frame implementation. Because "1110" is never used, it is taken over as the identifier of hello frame.

3.4 Procedure of relay

Before the RTS-CTS routine, a source node is required to broadcast a hello frame.

Every node which receives hello frame will check the fifth and the sixth field. If node k receives a hello frame from node i, it checks out relay_ID[k] to see if it's value is "1" or not. If it is, then node k changes the value of the third field to "1" in its relay table. That is responsible_for[i] = 1. Otherwise, the value of responsible_for[i] should be "0". Remarks that node k will change responsible_for[i] to "0" until sending the packet from node i out.

If the value of relay_ID[j] is "1" for node k which k is unequal to j. Node k should add the value of HD[j] by "1", meaning that node j is selected as a relay node once more. Because hello message is broadcasted, the value of HD is maintained simultaneously in this way.

Besides, every node receiving hello message must overwrite the PER field with the value of ER_ of the incoming hello message. In the beginning, PER value is calculated from the received packet using the formula mentioned in sub-section (1), and then stored in PER field.

But only the PER values from itself and the surrounding nodes are known and that's not enough. A node needs to be informed of the PER value of any pair of sender and receiver, and that will be useful in relay selection scheme in sub-section (5).

As a result, ER_ field is in use for passing PER values on. When node k receives a hello message from node i, it will replace PER[i][j] with ER_[j], except when j is equal to k. That's because the value of PER[i][k] is directly obtained and is needless to be altered.

3.5 Hot Spot Avoidance Relay Selection Scheme

This paper aims at hotspot condition which comes from the heavy relay load.

Before the cooperation procedure is executed, there are two judgments have to be made. One is to choose a relay route which packet error rate is as lower as possible. The second one is to avoid the hotspot occurrence. For the convenience of explaining this scheme, two states are defined below.

State 1: Form a candidate set

Fist of all, we pick up the nodes whose hotspot degree is not larger than the threshold and then put them into a candidate set.

The threshold is defined as follows.

$$\frac{\sum HD_i}{N} \qquad (12)$$

HD_i means the hotspot degree of node i, while hotspot degree represents the times of being used as someone's relay node. Besides, N stands for the total ad hoc nodes.

Once the candidate set is formed, next is to decide the appropriate one to be a relay. In this paper, we focus on the received-PER relay selection strategy, so we just pick up the one with the lowest PER out of the candidate set as the relay.

State 2: Select the appropriate node as relay node

In received-PER strategy, error rate of a transmission is required to be anticipated correctly in advance to make choice on which node should be the relay. Then, we will select the one with the lowest transmission PER.

Based on figure 4-1, there are two routes from the source to the destination, one is direct link (Source- Destination) and the other is relay route (Source-Relay-Destination). A relay route comprises two links, one is from the source to the relay, and the other lies between the relay and the destination.

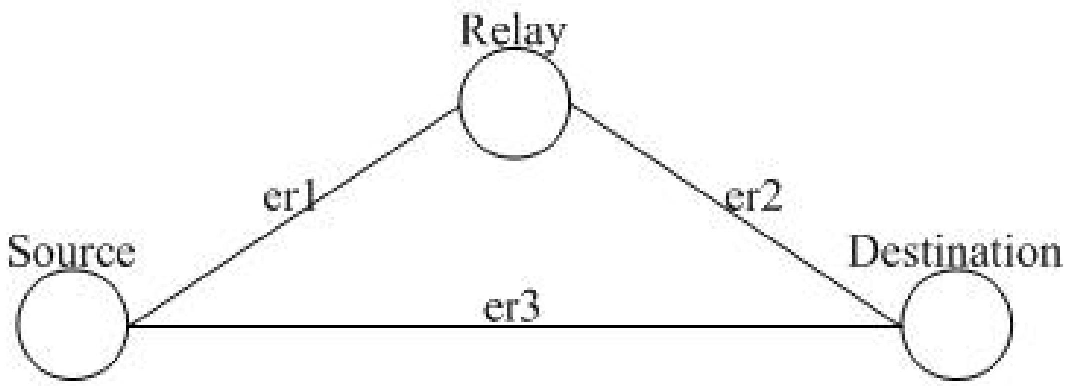

Fig. 4-1

From section Ⅱ, error rate of a link is able to be calculated, so er1, er2 and er3 in Fig. 4-1 are all known. Next paragraph is about the procedure of how to get the error rate of a route and subsequently of a whole transmission.

If an error packet reaches destination through the relay route, the error may happen either in link with error rate er1 or the other with er2. Then the packet error rate through this route is $1-(1-er1)\times(1-er2)$. On the other hand, if an error packet takes the direct link from source to destination, the error rate is er3 itself. For a cooperative network, if packet from the direct link is wrong, the total transmission still correct only if the one coming from the relay route is correct. In other words, only if the errors happen both in the direct link and the relay route, this packet is viewed as an error one. So, the transmission packet error rate can be written as

$$ERROR = er3\times(1-(1-er1)\times(1-er2)) \qquad (13)$$

where ERROR is the transmission error rate.

All in all, before any source start to transmit, it goes through these two states to find out the best relay node. If a multi-relay selection is considered, the two states will be executed repeatedly until any terminating condition is attained.

Chapter 4. Simulations and discussion

4.1 Basic Configuration

All the results are simulated by NS-2.

The global parameters are listed in table 5-1.

Table 5-1: Global parameters

Environment Size	1000 x 1000
Propagation Model	Shadowing
Reference Distance (m)	1
Simulation Time (sec.)	50
Node Transmission Radius (m)	550
Transmitting Power (mW)	0.4
Receiving Power (mW)	0.2
Idle Power (mW)	0.2
Data Rate (Mbps)	11
Queue Size	5

In order to make the simulation results more reasonable and comprehensible, shadowing model is adopted here as a propagation model in replacement of TwoRayGround, which belongs to the NS-2 default configuration [10]. In TwoRayGround, distance between two nodes is the only factor that influences the received power, which takes part in the derivation of SNR. However in real world, the received power at certain distance is a random variable due to multipath propagation effects, which is also known as fading effects. On the other hand, shadowing model considers fading as a major input to calculate the received power, and that's why it is more true to life and is applied generally.

The shadowing model consists of two parts. The first one is known as path loss. In path-loss model, received power at distance d according to a reference distance can be computed as follows.

$$\frac{P(d)}{P(d_0)} = (\frac{d_0}{d})^{\beta} \tag{14}$$

d_0 refers to the reference distance, which takes the value 1 in table 5-1. β is the path loss exponent. Table 5-2 lists some typical values of path loss exponent.

Table 5-2: The values of path loss exponent

Environment	Path loss exponent
Free Space	2
Urban Area	2.7~5
Line-of-sight	1.6~1.8
Obstructed	4~

From table 5-2, it is obvious that the larger values correspond to the more obstructions and hence less received power and SNR as distance between two nodes becomes larger.

From equation (14), the path loss can be measured in dB. We have

$$\left[\frac{P(d)}{P(d_0)}\right]_{dB} = -10\beta \log(\frac{d}{d_0}) \tag{15}$$

The second part of shadowing model reflects the variation of the received power at certain distance. It is Gaussian distribution and measured in dB as well. The overall shadowing model is (16).

$$\left[\frac{P(d)}{P(d_0)}\right]_{dB} = -10\beta\log(\frac{d}{d_0}) + X_{dB} \qquad (16)$$

where X_{dB} is a Gaussian random variable with zero mean and standard deviation σ_{dB}, which is also called shadowing deviation. Table 5-3 shows some typical values of shadowing deviation.

Table 5-3: The values of shadowing deviation

Environment	Shadowing Deviation
Outdoor	4~12
Indoor, line-of-sight	3~6
Indoor, obstructed	7~

In this simulation, shadowing deviation from 2 to 20 is applied to help us observe the performance.

There are two main metrics to compare the hotspot avoidance and non-hotspot avoidance schemes. They are relay load

$$\rho = \frac{n_r}{n_r + n_d} \qquad (17)$$

and transmission efficiency gain

$$g = \frac{n_{src} + n_d}{n_{sd}} \qquad (18)$$

(18) is for each node, and the total transmission efficiency gain is

$$g = \frac{\sum n_{src} + \sum n_d}{\sum n_{sd}} \qquad (19)$$

Note that in cooperative network, when the source node sends a packet, the packet is broadcasted to wherever within the transmitting range. That means both the destination and the relay node may count one time at the same time for this transmission. In order to avoid this redundant counting situation, (19) is altered into (20).

$$g = \frac{\sum n_{src} + \sum n_d}{\sum n_{sd} \cdot 2} \tag{20}$$

All the parameters in (17), (18) ,(19) and (20) are defined in table 5-4

Table 5-4 Variables of the metrics

Parameter	Meaning
n_r	The number of successful transmission of relay packet
n_d	The number of successful transmission of its own packet by direct link
n_{src}	The number of successful transmission of its own packet by relay node
n_{sd}	The number of successful transmission in traditional wireless network

ρ indicates the degree of being a relay. If the degree of relay gets bigger, this node spend most of the resource (queue, channel access) sending other's packets. That costs this node less chance to transmit the packets of its own and is as a result of bad transmission efficiency. g shows the performance of how much these two cooperation schemes gain. Because the initial condition of every node in traditional wireless network differs from each other, in order to reveal the real effects of theses two schemes without the impact of unequal initial node condition, "efficiency gain" instead of "efficiency" is our second metric.

There will be five simulations listed below. First two are designed manually. That means every node position, every source and destination of a transmission link, every starting and ending time of a transmission link, are all defined by author. In order to validate the conclusion from these two simulations, remaining three simulations are designed randomly.

In the last three simulations, a little change will be added to the definition of original HD threshold, and different HD-reset durations are tested to see if they could influence total throughput or not.

4.2 Result and analysis

Simulation 1:

Fig. 5-1 illustrates the node topology.

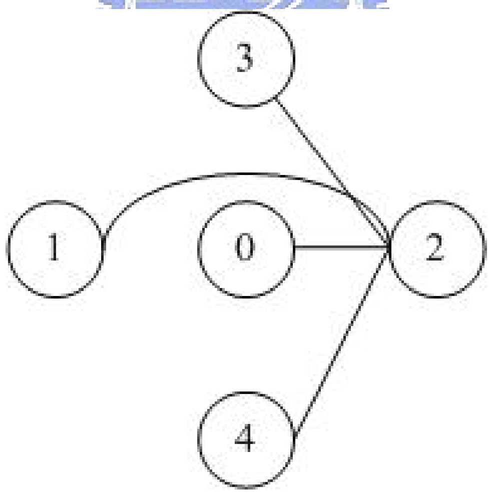

Fig 5-1 Topology of simulation 1

In Fig. 5-1, node 0, 1 ,3, 4 are the sources, and node 2 is the destination of these four sources. The distance of (0,1), (0,2), (0,3), (0,4) are all 200 meters.

Consider the original received-PER relay selection scheme first, for node 1, 3, 4, node 0 is absolutely the best one to be their relay node due to the geographical location of node 2. For node 0, relay selection depends on the error rate. It may be node 3 or node 4, even node 1 has the chance to be 0's relay. Then, node 0 undoubtedly has the largest possibility to be a hotspot.

On the contrary, received-PER relay selection with hotspot avoidance scheme deals with the centralization problem by balancing the chance of being a relay node. Fig 5-2 shows that the relay load distribution in hotspot avoidance relay selection scheme is more balanced.

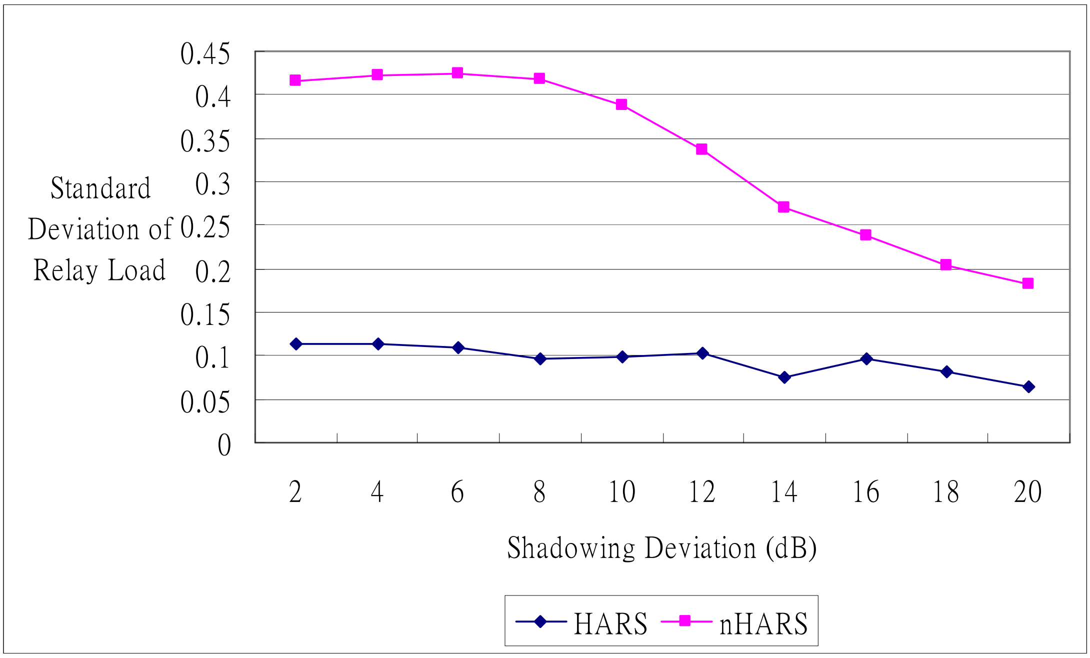

Fig. 5-2 Standard deviation of relay load distribution

In different shadowing deviation, hotspot avoidance relay selection scheme (HARS) keeps the value around 0.1, and the non-hotspot avoidance relay selection scheme (nHARS) does not. After the fourth point of nHARS, the line drops down quickly. That's because when the shadowing deviation gets larger, which indicate a more unstable and worse wireless transmission environment, the effect of geographical node distribution has less power to decide the transmission SNR. As a result, node 0 is not definitely the best choice to be the relay node. The centralization problem of hotspot condition is then alleviated.

Now, take a view of their total transmission efficiency gain in Fig. 5-3.

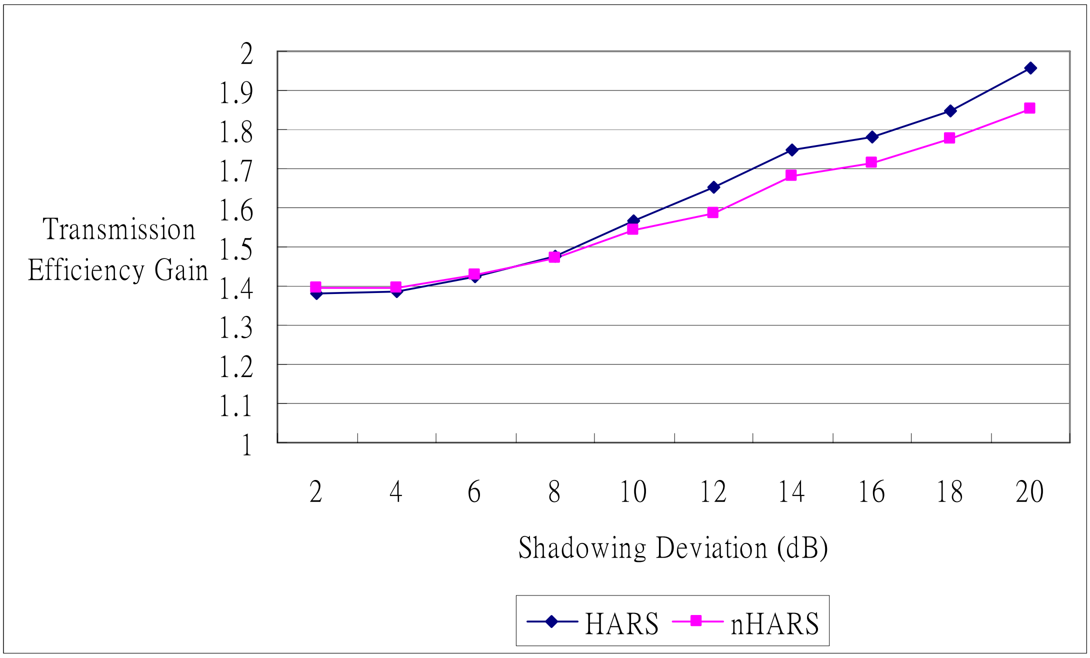

Fig. 5-3 Total transmission efficiency gain of the two schemes

Remark that before the fourth point, these two lines are almost equal. From the figure 5-2, we have a summary that the geographical node distribution has a large influence on the transmission quality. Back to Fig. 5-1, in HARS, although node 0 gets rid off the hotspot condition, it is at the cost of choosing another relay route which has a worse transmission quality from the system's point of view. So, the effects are neutralized.

After the fourth point, the centralization problem is somewhat alleviated little by little, that means the number of node 0 (Fig. 5-1) being selected as a relay is less and less. But the transmission condition of a hotspot gets down more and more seriously than the ordinary nodes according to the environment which is becoming worse and worse. Once nHARS scheme chooses a hotspot, the difference of the transmission quality between nHARS and HARS is more obvious. Of course, the shadowing deviation bigger than 12 is abnormal. So, Fig. 5-4 and 5-5 are necessary to be displayed to show the respective performance of each node in either scheme.

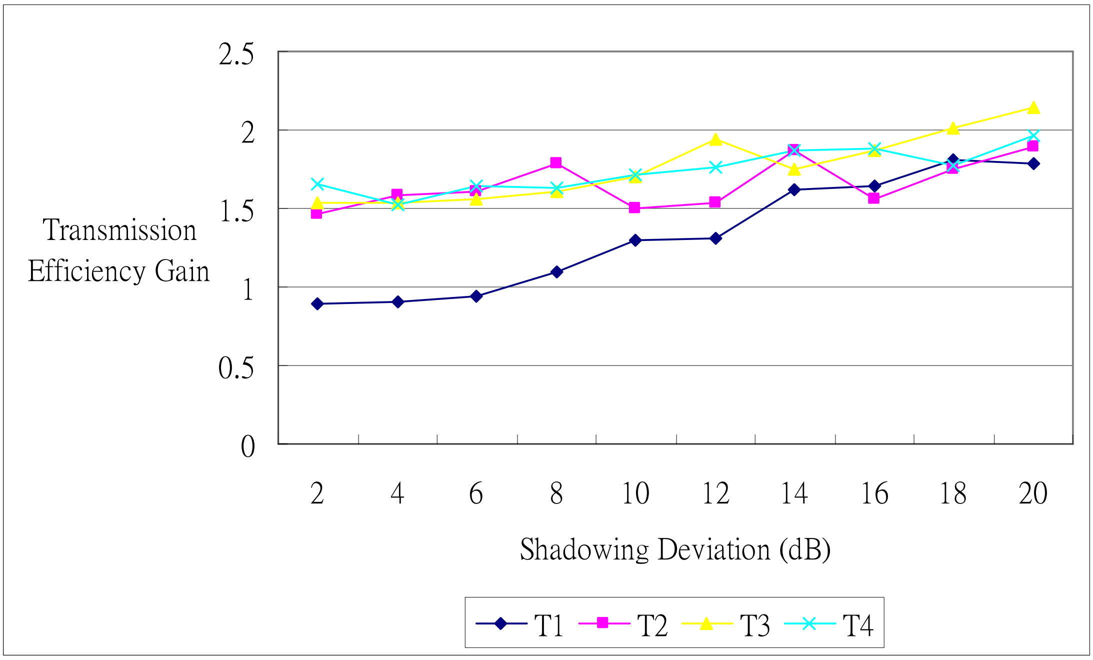

Fig. 5-4 Transmission efficiency gain of transmission in HARS

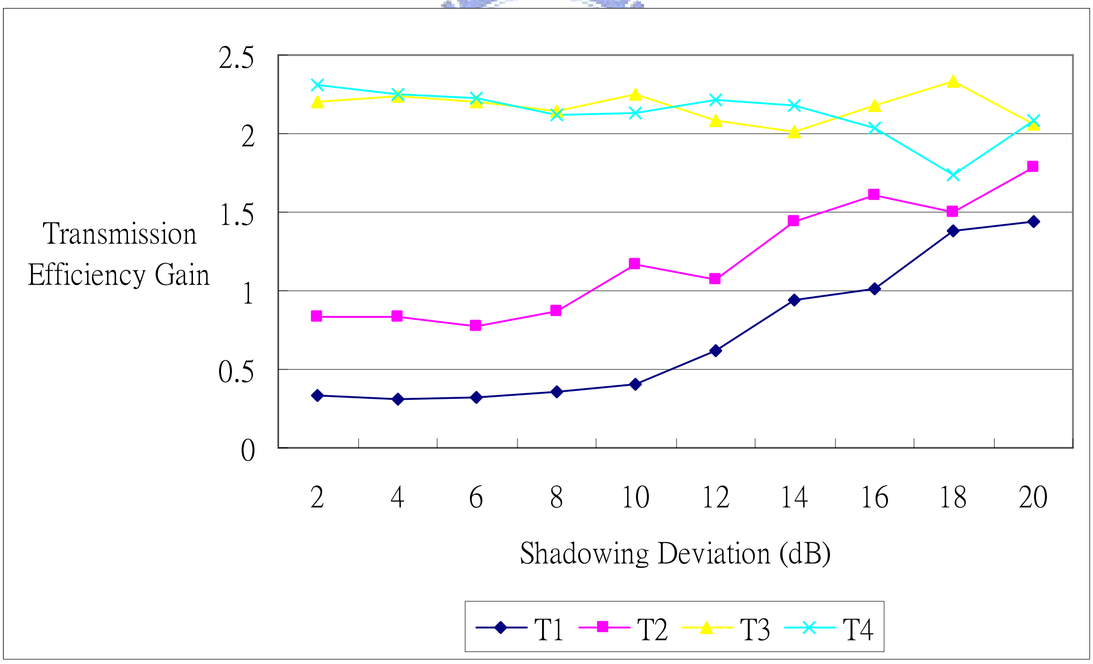

Fig. 5-5 Transmission efficiency gain of each transmission in nHARS

T1 is the shortened form of "Transmission id 1", which represents the data flow from node 0 to node 2. T2, T3, and T4 stand for flows from node 1, 3, 4 respectively to node 2.

In the former figure, behavior of T1 is distinctively lower than other three in the beginning. That's because node 0 is the nearest source of the others and has the best transmission efficiency. When cooperation applied to it, it has other packets to transmit in addition to the ordinary packets itself. Of course the efficiency gain is below "1" without question. But the gain will arise as the transmission quality becomes worse. It shows a precondition of when the cooperation is necessary and makes sense: A bad wireless transmission environment.

Let's emphasize the attention on T2 now.

In both figures, T2 performs quite differently. In HARS scheme, all the other nodes are able to be the relay node of node 1. That avoid the danger of hotspot condition, and the performance of transmission efficiency gain behaves better. On the contrary in nHARS scheme, node 1 constantly chooses node 0 as its relay. Once node 0 becomes a hotspot due to too many times of being a relay of others, packets from node 1 will be blocked and dropped in node 0. Then the performance of transmission efficiency gain is worse.

To confirm the above-mentioned reasons of why T1 in HARS and T1, T2 in nHARS are below "1", Fig. 5-6 reveals the primary results of T1 and T2 in traditional wireless network.

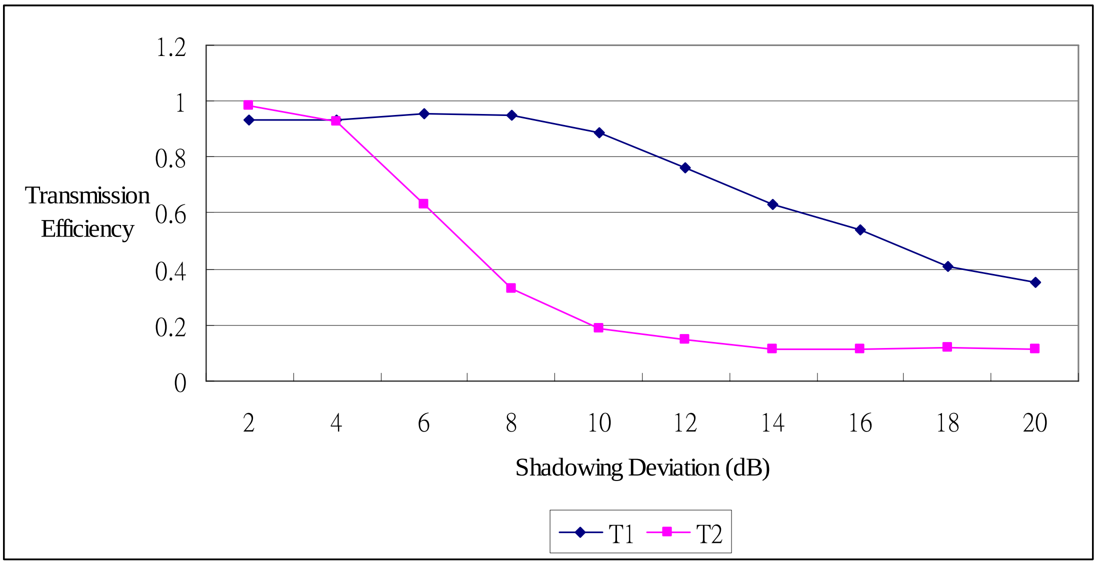

Fig. 5-6 The primary transmission efficiency of T1 and T2 in traditional wireless

It's apparent that the efficiency in T2 drops rapidly before the shadowing deviation achieves 10 dB, and the efficiency gain of nHARS (Fig. 5-5) on T2 is still below "1" before 10 dB. The only one reason is that hotspot condition happens to node 0, and node 1 only chooses node 0, which has already been a hotspot, as its relay.

Next, turn our attention to T3 and T4. They perform better in nHARS (Fig. 5-5) than HARS (Fig. 5-4). It's because node 3 and 4 merely transmit their own packets in nHARS while they must burden other node's packet as well in HARS.

This simulation is obviously developed for an environment which tends to grow a hotspot. Following is another case for all-source-all-destination.

Simulation 2:

Fig. 5-7 shows the topology.

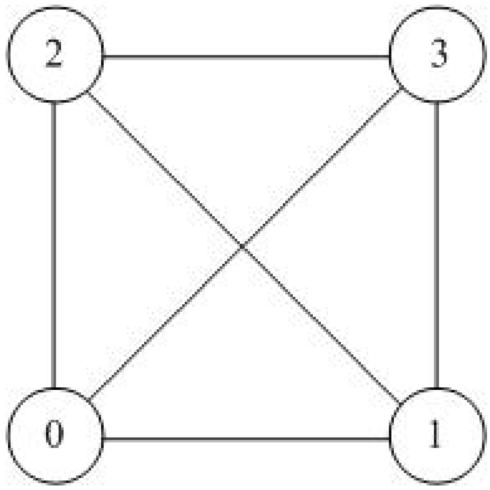

Fig. 5-7 Topology of simulation 2

Every node plays the role as a source and all the other three are its destinations.

In HARS scheme (Fig. 5-8), it is visible that before 10 dB, all the lines which stand for transmission efficiency gains are not diverse a lot and maintain roughly stable curves. Since 10 dB, they flutter drastically. It is as a consequence of the drastic change of the shadowing environment.

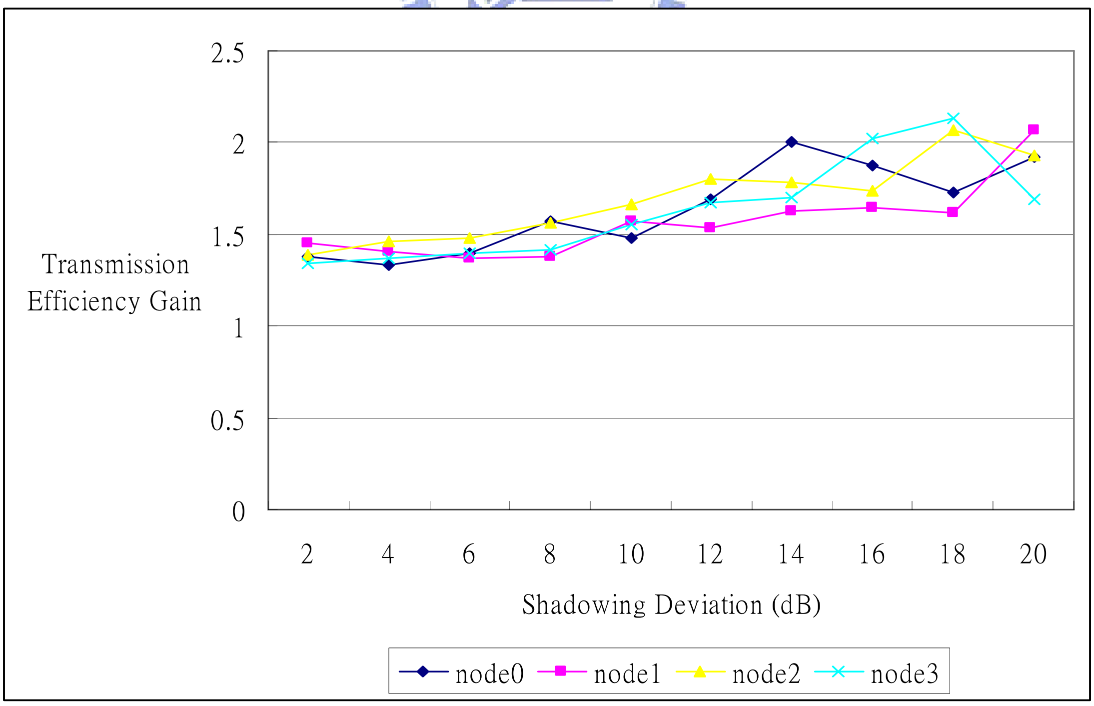

Fig. 5-8 Transmission efficiency gain for each node in HARS scheme

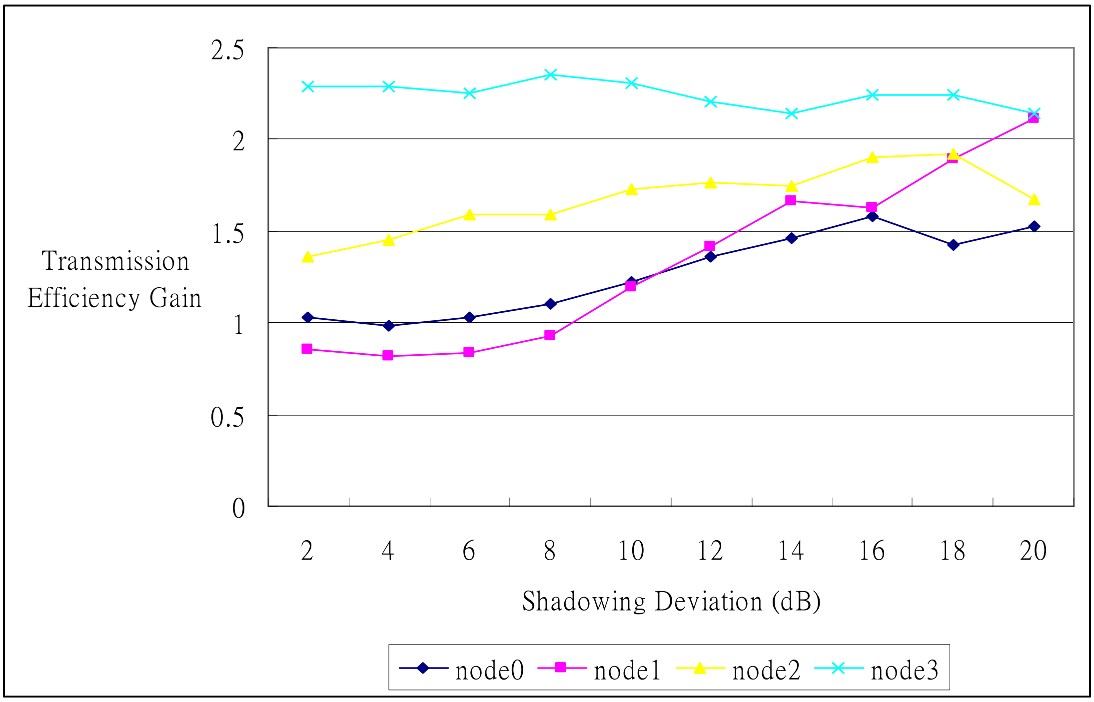

Fig. 5-9 Transmission efficiency gain for each node in nHARS scheme

The most interesting thing happens to nHARS scheme (Fig. 5-9). Data flow from node 3 gets unbelievable high transmission gain while flows from node 0 and 1 rise drastically. Maybe it is due to the incorrect implementation of nHARS scheme. In this implementation, when all the received-PER are all the same, source will choose the one with lowest node ID to be its relay. No ideas about how to select relay if their received-PER are equal from all the reference papers. Maybe it should be random strategy that should have been applied in the nHARS implementation.

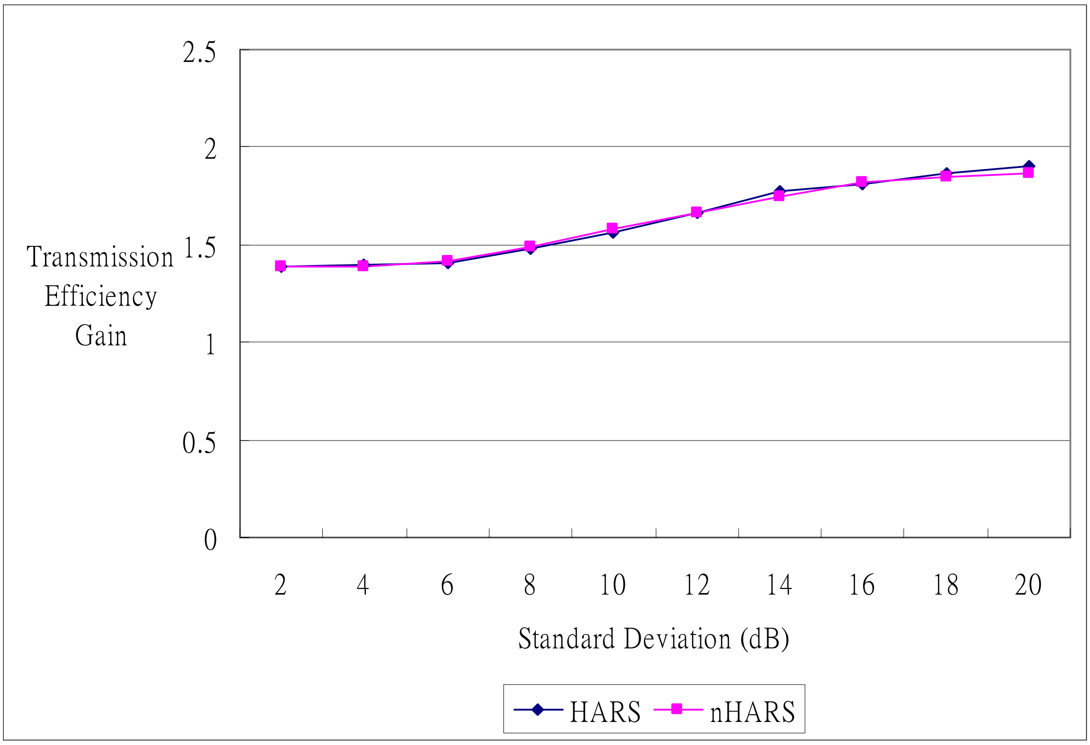

Fig. 5-10 Total transmission efficiency gains of HARS and nHARS

Then, take a look at the total transmission gain. Their performances are nearly identical due to the all-source-all-destination transmission pattern and the square topology. These special transmission pattern and topology make all the nodes seem identical and produce almost the same error rate for every link.

Both of these simulations use mean of all the hotspot degrees as the threshold.

$$HD\_threshold = mean \qquad (21)$$

where

$$mean = \frac{\sum HD_i}{N} \qquad (22)$$

Next, three variations of this threshold are presented in three simulations.

The following three simulations are randomly developed. They all contain 20 nodes and 40 traffic links. Nodes' locations are randomly distributed. For every link, the node IDs of source and destination are randomly selected, and the starting time and ending time of a transmission are randomized as well.

Simulation 3:

20 nodes and 40 links are randomly-generated five times. (forming five individual scenarios in next figure)

In this simulation, threshold is designed as that equal to mean of all the hotspot degrees plus node number (23).

$$HD\_threshold = mean + N \quad (23)$$

Why "plus"? It is observed that the original threshold definition (12) is too limited that the efficiency isn't good enough for most experiments instead of simulation 1 from many experiments which are not presented here. So, we extend the range of threshold definition, and the node number is used as a constant to be added to the original threshold.

There are five scenarios called S3_1, S3_2,…,S3_5. (Fig. 5-11)

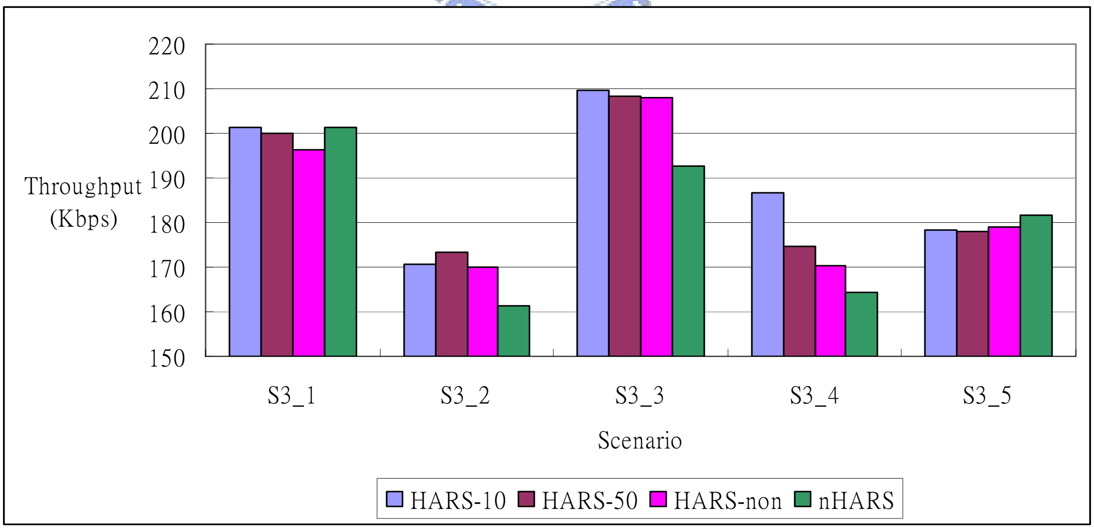

Fig. 5-11 Throughput of total transmission in five experiments in simulation 3

HARS-10 stands for hotspot avoidance relay selection scheme with HD-reset period of 10 seconds. That means all the hotspot degrees are reset to "0" for every 10 seconds (All the simulations in this paper are simulated for 100 seconds, so hotspot degree of every node is reset to “0” 10 times in HARS-10). HARS-non represents the original HARS presented in chapter 3.

It is obvious that in these five scenarios in Fig. 5-11, the results of throughput do not necessarily depend on HD-reset period. It is node topology and transmission pattern that indeed influence the throughput.

Simulation 4:

20 nodes and 40 links are randomly-generated five times.

In this simulation, another value of HD-threshold is defined as

$$HD\_threshold = mean + 2N \tag{24}$$

Why “2”? From Fig. 5-12, it is observed that in some scenarios such as S3_5 or S3_1, nHARS does a better job. Maybe the threshold (23) is still too limited, so “2N” substitute for “N” to be used as the second component of this new threshold (24).

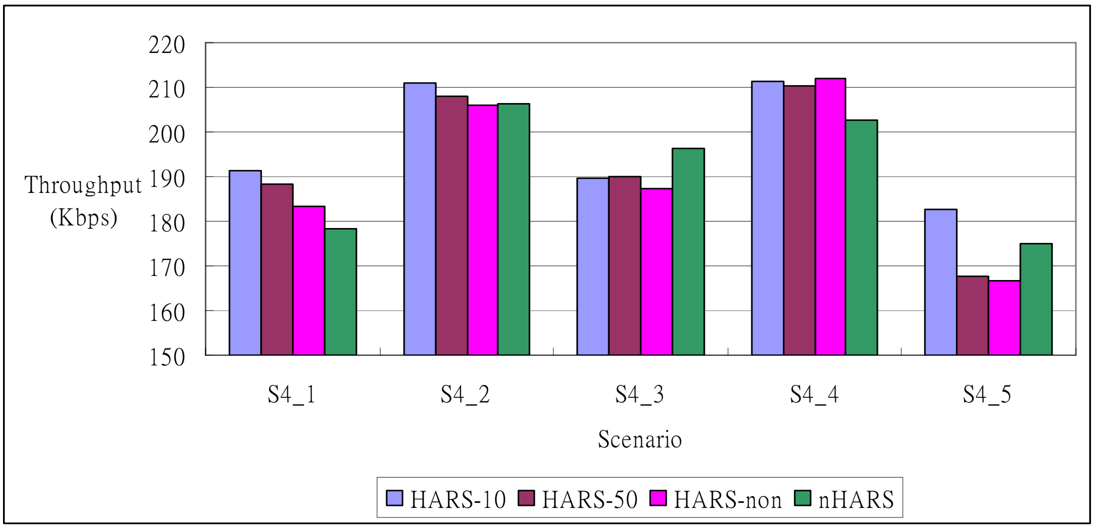

Fig. 5-12 Throughput of total transmission in five experiments in simulation 4

It is demonstrated again that cooperation performance doesn’t necessarily depend on HD-reset period.

Weather simulation 3 or 4, their definitions of HD threshold are in the form of

$$HD\_threshold = mean + Const. \tag{25}$$

From Fig. 5-11 or 5-12, HARS with different HD-reset periods do not necessarily perform better than nHARS. Instead, node topology and transmission pattern make a great impact on HARS performance.

Simulation 5:

20 nodes and 40 links are randomly-generated five times.

A new HD-threshold form is defined as followed

$$HD\_threshold = Const. \cdot mean \tag{26}$$

In this simulation, “2” is assigned to be the value Const. to see the performance.

$$HD\_threshold = 2 \cdot mean \tag{27}$$

From Fig. 5-13, we find that the throughput of each HARS scheme in any scenario is almost the same relative to former two simulations (simulation 3 and simulation 4). However, we can get the same conclusion. HD-reset period isn't the main factor that influences the throughput.

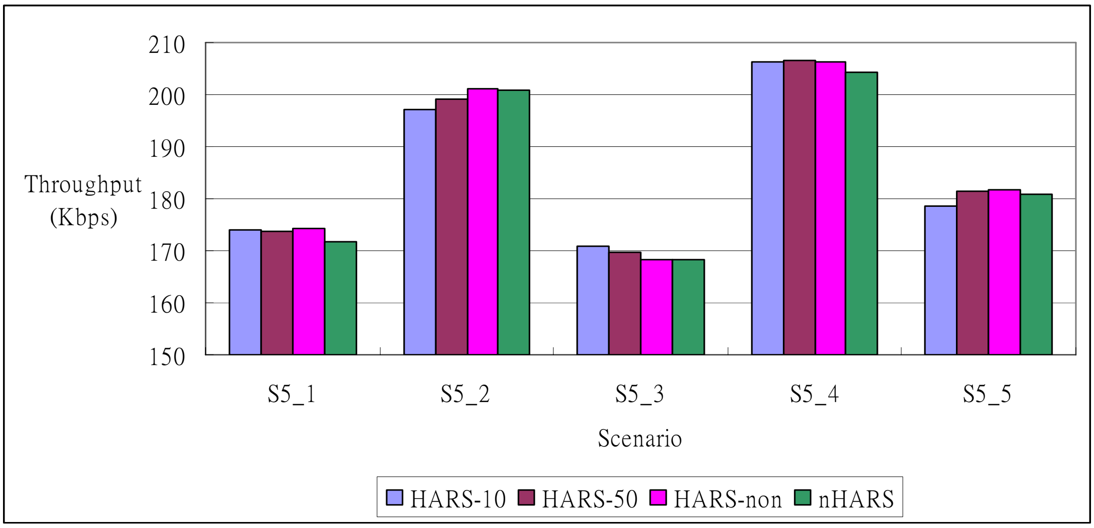

Fig. 5-13 Throughput of total transmission in five experiments in simulation 5

4.3 Discussion and summary

Either simulation 1 or 2, it is visible that the transmission gain gets better as the shadowing deviation grows larger. Simulation 1 and 2 are special cases. Node topology in simulation 1 makes the environment tend to grow a hotspot condition. It is observed that HARS can achieve a better transmission gain in this condition weather in total system view or respective view of every transmission link. In simulation 2, it's a traffic-balanced wireless environment and HARS has almost the same transmission gain as nHARS.

From these two simulations, we conclude that HARS works better in an unbalanced transmission environment in respective link's point of view.

In order to see how it works if it is applied to a dynamic transmission pattern or randomly-distributed node location with an amount of node and transmission link in total environment's point of view, we do simulation 3, 4 and 5. In simulation 3, we plus the original threshold with node number, while in simulation 4, we plus the original threshold with double node number. In simulation 5, we double the original threshold as a new threshold.

In addition to this, we're interested in the influence which is caused by periodically resetting the HD, so we defined HARS-10 and HARS-50 which mean that hotspot degrees are reset to "0" for every 10 seconds and 50 seconds respectively.

In simulation 3, 4 and 5, status of respective transmission link isn't the focus anymore. We put our emphasis on throughput. Besides, it is difficult to analyze the performance of every link, so we just compare the total system throughput. Remember that different initial transmission efficiency (transmission efficiency without cooperation) in every link is why we compare efficiency gain instead of efficiency. For now, because there is only one initial total transmission efficiency (total transmission efficiency without cooperation), efficiency "gain" does not necessarily act as a metric. However, throughput is a more popular metric than efficiency, so we use throughput rather than efficiency as our metric in simulation 3, 4, and 5.

Whether in simulation 3, 4, or 5, we find that throughput doesn't depend on reset period. If scenario or topology is generated like those of simulation 1, HARS performs well. Otherwise, HARS sometimes has a worse performance.

Chapter 5. Conclusions and future work

In this paper, a modified relay selection scheme named HARS is proposed to improve transmission efficiency of a hotspot and make its transmission more reliable and efficient. Although HARS doesn't necessarily achieve more total transmission efficiency or throughput in some conditions, it is proved that the nodes with heavy relay traffic load benefit from this scheme.

Besides original HARS (21), simulations also test the results of modified-HARS, such as HARS-10, HARS-50, in different threshold forms, like linear formula (25) and scalar formula (26).

In the viewpoint of the overall environment, transmission efficiency or throughput mainly depends on the node topology and transmission pattern. However in the viewpoint of respective node, HARS is able to make hotspot more transmitting efficient.

In the future, shadowing model could be replaced by Ricean or Rayleigh model to see the performance. Besides, in this paper, the number of acting as a relay is counted to avoid hotspot condition, but the counting method isn't exact enough. If we want a global improvement, buffer capacity or dropping rate should be counted to decide who the relay node is, just like the works presented in [7].

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